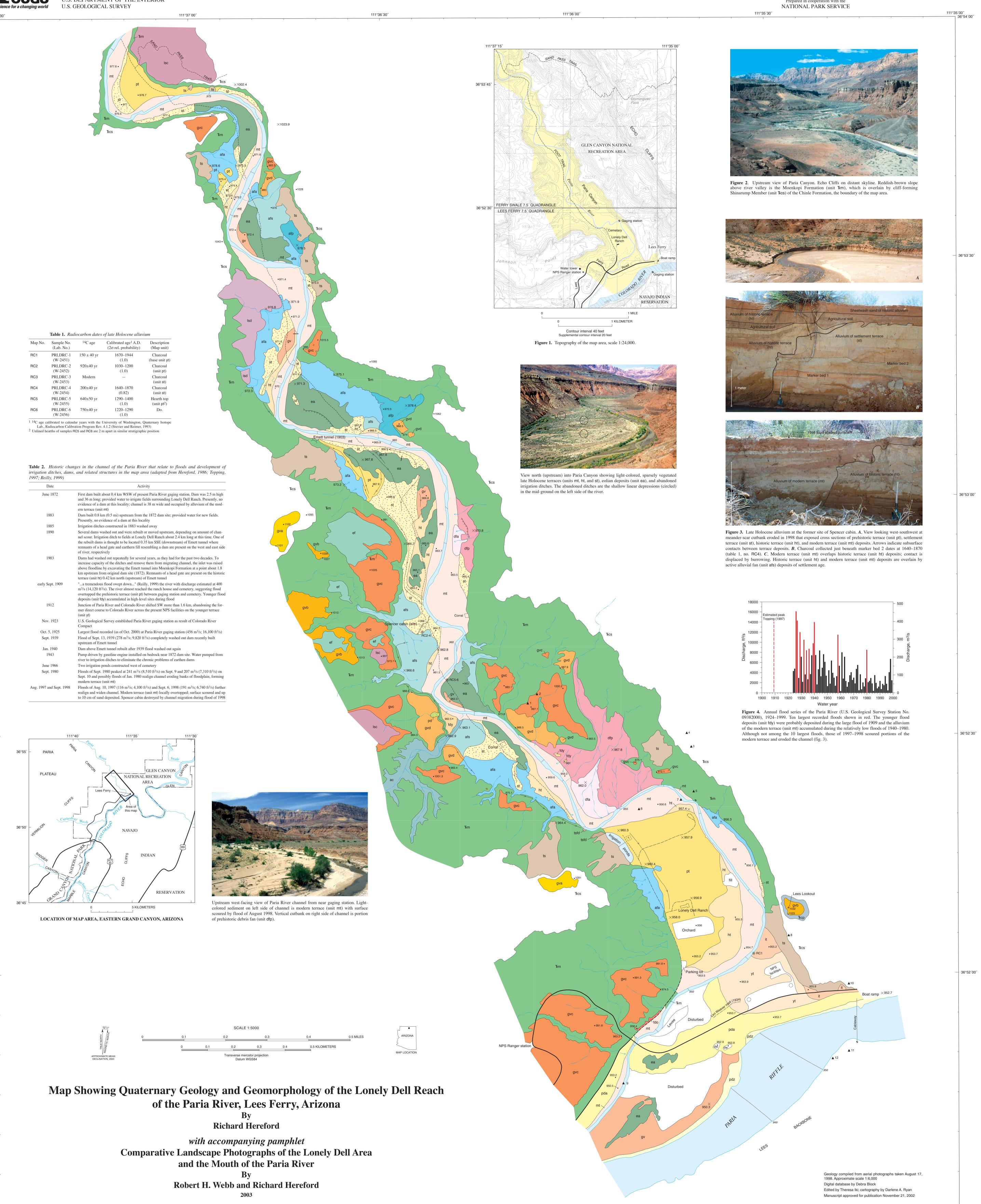
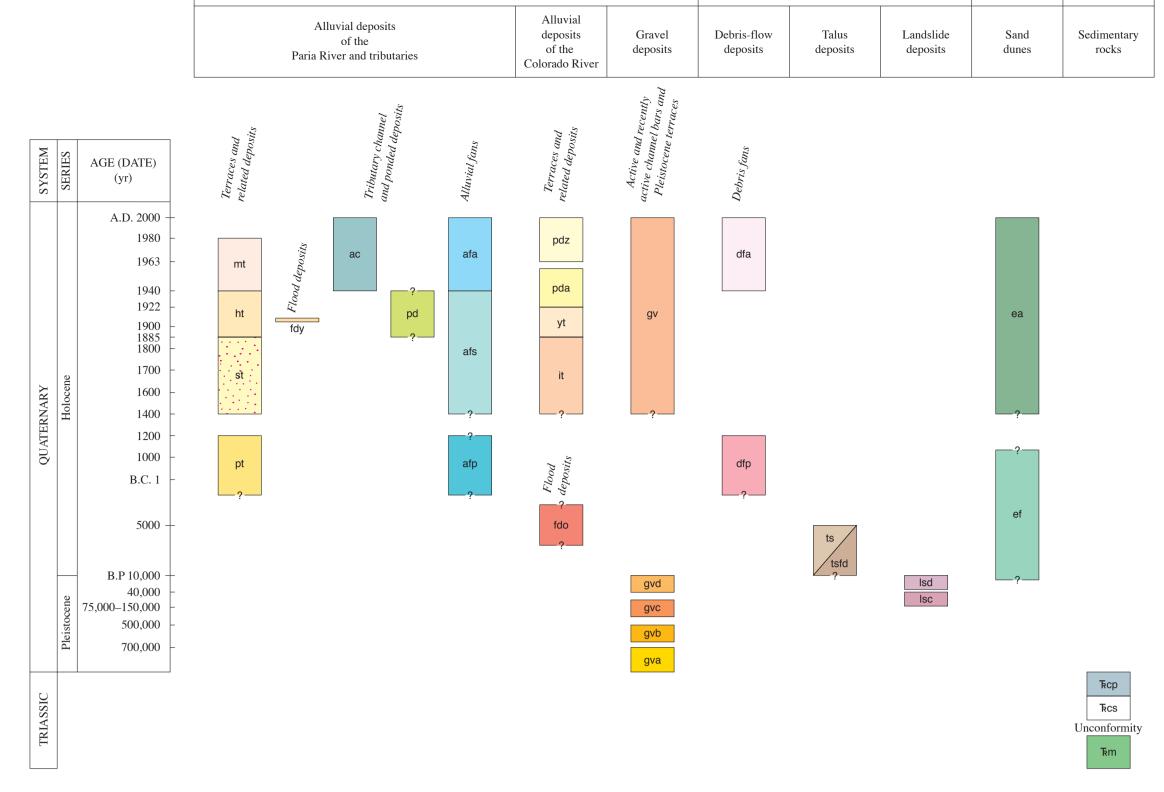
U.S. DEPARTMENT OF THE INTERIOR GEOLOGIC INVESTIGATIONS SERIES I–2771 Prepared in cooperation with the U.S. GEOLOGICAL SURVEY NATIONAL PARK SERVICE Pamphlet accompanies map





ALLUVIUM

CORRELATION OF MAP UNITS

COLLUVIUM

## DESCRIPTION OF MAP UNITS

[All dates are anno Domini (A.D.) unless otherwise noted] ALLUVIUM

Alluvial deposits of the Paria River and tributaries Terraces and related deposits

mt Modern terrace (1940–1980) of Hereford and others (2000)—Light-colored, very fine grained sand with thin lenticular beds of gravel and continuous beds of silty sand; thickness 2-4 m. Deposits are well exposed near Paria River gaging station where they were described and dated by Hereford (1986). Near former site of Spencer cabin (Reilly, 1999; structure was removed by channel migration during floods of September 1998), modern alluvium has inset stratigraphic relation with alluvium of historic terrace (unit ht). Unit includes active channel and floodplain of Paria River. Settlement-era irrigation ditches not present on this terrace. Floods in summer of 1997 and 1998 locally scoured surface of unit and eroded banks. Unit mt correlates with the modern alluvium of the Virgin River and other southern Colorado Plateau streams (Hereford and others, 1996a; Hereford, 2002) Historic terrace (1885–1940)—Light-colored, very fine grained to fine-grained sand.

Present locally 1–2 m below settlement terrace (unit st) in abandoned meanders and other protected sites at contact with settlement terrace. Settlement-era irrigation ditches typically not present on this terrace, although a ditch covered by 1 m of sheetwash gravel and alluvium is present below terrace near former site of Spencer cabin and a headcut was constructed on the terrace north of Emett tunnel. Terrace

equivalent to the older channel alluvium of Hereford (1986) **Settlement terrace** (1400–1885)—Light-colored, very fine grained silty sand interbedded with reddish sand and pebble gravel of hillslope origin near margin of alluvial valley. Well stratified with beds 10–40 cm thick. Unit is typically 3–4 m above river and is disconformable with alluvium of historic and modern terraces. Well exposed in fresh (as of Oct. 2000) meander scar near former site of Spencer cabin. Charcoal at this locality dated 1640–1870 (table 1, no. RC4). Most settlement-era irrigation ditches and related structures were constructed on this terrace. Near north end of map area close to spot elevation 977.4 m, large, mature to senescent cottonwood trees rooted 0-75 cm below terrace date between 1840-1890 (D. Grow, written commun., 2000). Settlement terrace (unit st) is equivalent to settlement terrace and Naha alluvium of southern Colorado Plateau (Hereford and others, 1996a; Hereford, 2002) **Prehistoric terrace (late Holocene to 1200?)**—Light-colored, very fine grained silty

sand typically overlain and interbedded with reddish gravel of sheetwash origin. Well exposed at Spencer cabin site where it is overlain disconformably by the settlement alluvium and an alluvial fan of settlement age (unit afs). Charcoal from near base of unit within 20 cm of contact with alluvium of settlement terrace (unit st) dates to 1030–1200 (table 1, no. RC2). Prehistoric alluvium underlying eolian sand (unit ea) derived from settlement alluvium (unit st) is penetrated by two unlined fire hearths that date to 1290-1400 and 1220-1290 (table 1, nos. RC5 and RC6). Near Lonely Dell Ranch, archeologic remains of Pueblo-II age (ca. 1050–1200) are present on terrace (H.C. Fairley, oral commun., 2000). Prehistoric terrace equivalent to the Tsegi alluvium, prehistoric terrace, and alluvium of Pueblo-II age of southern Colorado Plateau and Colorado River in Grand Canyon (Hereford and others,

Younger flood deposits (1909)—Light-colored, very fine grained silty sand of Paria River origin. Unit is older than modern terrace (unit mt) and has inset relation with settlement age alluvial fan (unit afs), although 0.55 km northwest of gaging station on east side of river younger flood deposits overlie prehistoric debris fan (unit dfp). Unit probably deposited by flood of 1909, the largest post-1880 flood of the Paria River (Topping, 1997; Reilly, 1999)

Tributary channel and ponded deposits Active channel deposits (1940–2000)—Light-colored and light-red sand with pebble and small cobble gravel. Confined to relatively wide reaches of ephemeral channels that flow in direct response to rainfall Ponded deposits (1871?–1940?)—Light-colored, very fine grained silty to clayey sand. Present in channel of small tributary west of spot elevation 962.5 m that was

impounded by construction of settlement-era irrigation ditch Active alluvial fan deposits (1940–2000)—Light-red, pebble- to cobble-size gravel interbedded with alluvium of Paria River origin; forms roughly fan-shaped deposits overlying terraces of all ages afs Alluvial fan deposits of settlement age (1400?–2000)—Light-red, pebble- to cobblesize gravel in roughly fan-shaped deposits. Toes of fans are truncated by deposits of

historic and modern terraces. Fan surfaces are only slightly weathered, and active channels are present locally Alluvial fan deposits of prehistoric age (late Holocene)—Light-red, pebble- to cobblesize gravel in roughly fan-shaped deposits. Margin of prehistoric fans are truncated by younger fans and terraces. Surface of fans are distinctly weathered with numerous disintegrated clasts of sandstone and siltstone derived from Moenkopi Forma-

Alluvial deposits of the Colorado River

Terraces and related deposits Post-dam zone (1963–2000) of Hereford and others (2000)—Very fine grained, lightcolored sand and gravel; deposits poorly preserved; thickness 0-2 m. Elevation ranges from 949–952 m near cableway. Mainly an erosional zone along margin of Colorado River. Sand spottily distributed on gravel; bounded by steep, erosional cutbanks adjoining older terraces. Dense groves of small, relatively mature nonnation in 1963 contemporaneous with closure of Glen Canyon Dam 27 km upstream

pda Pre-dam alluvium (1922–1958)—Well-bedded, very fine grained, light-colored silty sand with beds 10–20 cm thick; thickness 3–4 m on south side of Paria River west of National Park Service (NPS) facilities. Interbedded with lower part of alluvium of modern terrace of Paria River (unit mt) at mouth of Paria Canyon. Elevation ranges from 951–953 m near cableway. Mature tamarisk trees in dense groves partly buried in alluvium are typical; part of unit post-dates 1935 on basis of ring counts from tree rooted beneath terrace on south side of river upstream of Colorado River gaging station. Driftwood deposits (unit dw) on terrace contain abundant cut-andmilled wood and cans and bottles dating from mid-1950s. Equivalent to pre-dam

terrace of Hereford and others (2000)

Younger terrace (1884–1921) of Hereford and others (2000)—Well-bedded, very fine grained, light-colored silty sand with beds 10–20 cm thick; exposed thickness 4–5 m at south side of Paria River north of NPS facilities. Unit interbedded with alluvium of Paria River at mouth of Paria Canyon. Elevation is 953.9 m near parking area at mouth of Paria River. Tamarisk locally abundant on terrace; trees are rooted on surface and post-date deposition; ring counts indicate germination in early to mid-1960s. Charcoal from near base of unit dated at 1670–1944 (table 1, no. RC1). Younger terrace is probably equivalent to historic terrace (unit ht) of Paria River based on similar elevations. Inset, erosional relation with intermediate terrace (unit it) Intermediate terrace (1400?-1883) of Hereford and others (2000)—Well-bedded, very fine grained, light-colored silty sand with beds 10-20 cm thick; contains interbedded sheetwash sand and pebble gravel near tributaries; thickness 5–6 m at south side of Paria River north of NPS facilities. Unit interbedded with alluvium of Paria River at mouth of Paria Canyon. Elevation ranges from 955.2–955.9 m. Tamarisk

and willow not present on terrace. A photograph of north bank of Colorado River

taken in 1873 shows intermediate terrace (Turner and Karpiscak, 1980, pls. 32A,

33A; photograph site 11); at that time, terrace was densely covered with rabbitbrush

and fresh-appearing driftwood. Intermediate terrace is equivalent to settlement terrace (unit st) and Naha alluvium of southern Colorado Plateau (Hereford and others,

1996a; Hereford, 2002) Older flood deposits (early to middle Holocene) of Hereford and others (2000)—Very fine grained, distinctive light-greenish-gray silty sand with finely interbedded silt and very fine sand couplets 1–5 mm thick that form low-angle cross strata; exposed thickness 3–5 m. Elevation of deposit corresponds to extrapolated gage height (Colorado River gaging station) of 18.7–23.3 m (59.9–76.3 ft). By comparison, the largest recorded flood (July 1884) has estimated gage height of only 9.6 m (31.5 ft), corresponding to discharge of  $8,500 \text{ m}^3/\text{s}$  (300,000 ft<sup>3</sup>/s)

Active and recently active channel bars and Pleistocene terraces Gravel deposits, undivided (1400?–2000)—Gravel composed mainly of sub-rounded to rounded pebbles to small cobbles of local Mesozoic formations, rounded small cobbles of quartzite, pinkish pebbles of Claron Formation derived from headwaters of Paria River, and along Colorado River, minor well-rounded cobbles of far-travelled porphyritic rocks; thickness 1–4 m. At mouth of Paria River unit forms a broad extensively reworked fan that deflects Colorado River to south. In Paria Canyon, unit forms gravel bars in active channel and inactive bars associated with the modern (unit mt), historic (unit ht), and settlement (unit st) terraces. The latter two gravels are very lightly weathered with moderately formed to well-formed cryptobiotic crusts covering matrix between clasts

and rounded to well-rounded pebbles and small cobbles of local Mesozoic formations and well-rounded quartzite and porphyry and pinkish pebbles of Claron Formation from headwaters of Paria River; thickness 15 m. Matrix is moderately sorted coarse sand. Base of gravel is 8-9 m above river. Gravel on surface is distinctly varnished. Unit has steeply dipping concave contact with underlying Moenkopi Formation. Probably equivalent to younger gravel deposits (unit gvy) of Hereford and others (2000) based on height above Paria River Level c gravel deposits (late Pleistocene)—Gravel composed mainly of sub-rounded and rounded pebbles and small cobbles of local Mesozoic formations and well-

Level d gravel deposits (latest Pleistocene)—Gravel composed mainly of sub-rounded

rounded quartzite and porphyry and pinkish pebbles of Claron Formation from headwaters of Paria River; thickness 17-28 m and 10-33 m along Colorado and Paria Rivers, respectively. Base of gravel ranges from 14-26 m above Colorado River and from 14–22 m above Paria River. NPS ranger station is built on terrace formed by this gravel. Level c gravel (unit gvc) is equivalent to older gravel (unit gvo) of Hereford and others (2000) Level b gravel deposits (early to late Pleistocene)—Gravel composed mainly of subrounded and rounded pebbles and small cobbles of local Mesozoic formations and well-rounded quartzite and porphyry and pinkish pebbles of Claron Formation from

headwaters of Paria River; thickness 10-12 m. Base of gravel is 73 m above Colorado River at Lees Lookout and 51-65 m above Paria River. Gravel on surface is deeply varnished and heavily decomposed Level a gravel deposits (early to middle Pleistocene)—Lag gravel of well-rounded quartzite pebbles and small cobbles; thickness 1 m. Base of gravel is 140 m above

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—2003 111°35′00″

111°35′30″

111°36′00″

111°36′30″

## COLLUVIUM Debris-flow deposits

Debris fans Active debris-flow deposits (1940–2000)—Gravel consisting mainly of angular to subangular cobble to small and medium boulder-size sandstones of Moenkopi Formation (unit km) and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation (unit \( \mathbb{R} \mathbb{C} \)); clast to matrix-supported texture; thickness 1–2 m.

Deposited on and probably interfingers with alluvium of the modern terrace (unit mt). Boulders are fresh appearing and unweathered Prehistoric debris-flow deposits (middle to late Holocene)—Gravel similar to unit dfa above except boulders are distinctly varnished and beneath surface; undersides of boulders have incipient Stage-I carbonate morphology of thin discontinuous white coatings of calcium carbonate. Two small rectangular stone structures of probable Pueblo-II affinity (ca. 1050–1200) are present on prehistoric fan 0.5 km northwest of Paria River gaging station

EOLIAN BEDROCK

Talus, undivided (latest Pleistocene? to Holocene)—Mainly sheets of small to medium boulder-size blocks of Shinarump Member of the Chinle Formation (unit Rcs) on steep slopes of Moenkopi Formation (unit \( \mathbb{R}m \)) beneath cliffs of sandstone. Talus deposits are moderately dissected and expose underlying bedrock. Sandstone blocks are distinctly varnished

Talus with interbedded flood deposits (latest Pleistocene? to Holocene)—Similar to unit ts above except talus contains multiple beds of very fine grained greenish-gray silty sand resembling Colorado River flood deposits; present at two localities 0.4 km west-southwest of Paria River gaging station. Deposits are elevated far above any known flood level of Colorado River Landslide deposits

Landslide deposits of level d gravel (latest Pleistocene)—Poorly sorted blocks of

brown and red sandstone and somewhat coherent, chaotically rotated segments of Glen Canvon Group (Mesozoic) sandstone intermixed with bentonitic clays of Petrified Forest Member of the Chinle Formation (unit Rcp). Landslide originated from slope failure of bentonitic shales and subsequently slid to position of level d gravel. Stratigraphic relations suggest landslide and gravel are contemporaneous Landslide deposits of level c gravel (late Pleistocene)—Similar to unit lsd above except that landslide slid to position of level c gravel

Active eolian deposits (1400?–2000)—Very fine grained to fine-grained, moderately well sorted sand forming lightly vegetated active dune fields; thickness 1–3 m. Along Paria River, sand derived from reworking and deflation of adjacent alluvial deposits. Deposits locally cover settlement-era irrigation ditches **Falling dunes (late Pleistocene to Holocene)**—Very fine grained to fine-grained, moderately well sorted sand forming sand sheets that descend steep slopes of level b and

## Sedimentary rocks

c gravel deposits. Sand derived from reworking of sand in gravel deposits

Chinle Formation (Upper Triassic) Petrified Forest Member—Bentonitic mudstone and claystone; thickness 190 m (Phoenix, 1963); typically forms talus-covered slopes. Not present in map area Shinarump Member—Conglomeratic sandstone cross-stratified in lenticular beds 50–150 cm thick; sharp erosional contact with underlying Moenkopi Formation;

thickness 0-50 m (Phoenix, 1963). Sandstone forms distinctive light-brown cliff above inner valley of Paria Canyon; base of sandstone is outer boundary of map Moenkopi Formation (Middle? and Lower Triassic)—Gypsiferous, pale-red to darkbrown, slope-forming mudstone, siltstone, and silty limestone; thickness 100–140 m (Phoenix, 1963)

• 960.3 **Spot elevation**—In meters, determined photogrammetrically

:965 Channel elevation—1-m contour elevation in channels of Paria and Colorado Rivers; channel elevation indicated at 5 m intervals  $\times$ 960.3 **Survey control point**—Elevation in meters

**Photograph site**—Number corresponds to photograph site number in pamphlet

 Ephemeral stream **✓** Ephemeral stream ending at arrow

Erosional scarp—Hachures at base of scarp ---- Dirt road

---- Graded road, dirt

——— Paved road

Head gate of abandoned irrigation ditch

**├ Irrigation-ditch tunnel** Wood or stone structure—Mapped shape is variable

dw **Driftwood** 

Disturbed Disturbed area of mostly covered, unmappable surficial geologic materi-

## als—Disturbance caused by construction and presence of roads, vehicle parking lots, gravel pits, channel-control structures, and National Park Service facilities

The Lonely Dell reach of the Paria River is in the lower Paria Canyon (fig. 1), a colorful rela-

tively open valley (fig. 2) eroded into the Moenkopi Formation (Triassic). The valley lies nearly 600 m below the Echo Cliffs on the east and 900 m below the Paria Plateau on the west. Paria Canyon is a strike valley aligned with the Echo Cliffs monocline, a major northwest trending flexure with more than 1 km of uplift. The Paria River, a perennial stream, joins the Colorado River downstream of Lees Ferry, which is near the beginning of the Grand Canyon of the Colorado River. This large-scale surficial geologic map shows the age, distribution, and origin of Quaternary deposits in the river valley. Information about recent geologic activity is necessary to understand the natural variability of the river system as well as the rates, magnitudes, and processes of environmental change. The alluvial history of the past thousand years is of particular interest as it relates to how the climate of the Medieval Warm Period (ca. 1000–1400), the Little Ice Age (1400 to the middle- to late 1800s), and recent global warming (late 1800s to present) affected the alluvial system. This history provides clues about how the Paria River, and others like it, may respond to future climate variation brought about by increasing concentrations of greenhouse gasses. The alluvial history of the Paria River is especially important as a research topic because of the long, continuous record of streamflow measurements. Beginning in 1923, this record is the longest of any stream originating on the Colorado Plateau. The long-term streamflow patterns at the Paria and Colorado River gaging stations reveal environmental changes of the 20th century, including arroyo cutting, droughts, and floods (Andrews, 1990, 1991). The Lees Ferry/Lonely Dell area has a long and rich cultural history (Rusho and Crampton,

1992; Reilly, 1999). The area has been an important Colorado River crossing since prehistoric times. It is the only accessible ford of the Colorado River between two virtually uncrossable canyons, Glen Canyon and Marble Canyon. The first written description of the area is the Dominguez-Escalante Journal (Chavez, 1976, p. 93–95), an account of an expedition through the Southwest in 1776. The expedition camped on the banks of the Paria River below Lees Lookout from October 27 to November 1, 1776, while trying unsuccessfully to cross the Colorado River. They left the area via Sand Pass Trail and forded the Colorado River at Crossing of the Fathers, 40 km northeast of the study area. As they rode north up the Paria River valley, they passed over what is now the settlement terrace (unit st). Almost a century later, the area was visited and described by John Wesley Powell during his explorations of the Colorado River. In late 1871, the ferry and Lonely Dell Ranch were established by John D. Lee. Because of its regional importance as a river crossing, its spectacular scenery, and the presence of two stream gaging stations, the area has been photographed numerous times beginning in 1872 (Turner and Karpiscak, 1980). These photographs are reproduced and interpreted in the accompanying pamphlet by R.H. Webb and Richard Hereford. The photographs show clearly that the channels of the Paria and Colorado Rivers have changed substantially in the intervening 123 years. In modern times, the area is important for recreation including sightseeing, hiking, and fishing, and as a launching point for whitewater raft trips through Grand Canyon. The alluvial deposits are grouped into two principal types and ages. The older deposits are mainly gravel deposited by the Paria River and Colorado River during the middle to latest Pleisto-

cene. These deposits occur at four distinct topographic levels ranging from about 10 to 140 m above the present river channel. The gravel deposits record the downcutting and backfilling of the river during the past 700 ka (ka = 1,000 yrs). The younger deposits are primarily sand deposited during the late Holocene up to and including the modern era. Based on the streamflow record and contemporaneous alluvial history, aggradation and erosion of these valley- and channel-fill deposits result largely from changes in how often large floods occur, which in turn is relates to climate variations, particularly episodic increases of runoff-producing precipitation.

PLEISTOCENE GRAVEL DEPOSITS

Where well preserved, the gravel deposits are up to 33 m thick. The basal contact with bedrock is concave reflecting the configuration of the underlying bedrock channel. Four distinct levels are present: levels and with heights above the Paria River measured from the base of the gravel of 140, 51-65, 14-22, and 8-9 m, respectively. Thus, Paria Canyon has been downcut 140 m through bedrock since deposition of the a-level gravel (unit gva). Downcutting to the present level of the river was episodic occurring four times. Each downcutting, however, was followed by backfilling or channel filling that together equaled or exceeded the 140 m of downcutting, because the cumulative gravel thickness is at least 140 m. The surfaces of the gravels are heavily weathered. Cobbles and boulders are mainly resistant quartzites. Their surfaces have dark coatings of rock varnish and the undersides are rubified or have

rinds of calcium carbonate up to 1 mm thick. This degree of weathering and the height of the depos-

its above the two rivers indicates they are Pleistocene. Moreover, the degree of weathering and the

height above the river are similar to gravels of known middle to late Pleistocene age in the Little

Colorado River valley (Ulrich and others, 1983) 110 km south-southeast of the study area. Beyond this, however, the ages of the gravels are poorly known.

In the eastern Grand Canyon 100 km downstream of Lees Ferry, a sequence of terrace-forming gravels were dated by Machette and Rosholt (1991) and Lucchitta and others (1995). Although these workers used different dating techniques, their results agree broadly within the analytical error of the methods when the same levels were dated. Lucchitta and others (1995) report ages between about 60-80 ka for deposits ranging from 17 to 30 m above the river and 100 ka for those between 44-46 m above the river. These heights correspond to levels 3-4 and level 5 of Machette and Rosholt

(1991) that are 10–40 and 150 ka, respectively. These authors dated two substantially older terraces, levels 6 and 7, that are 90 and 135 m above the Colorado River whose ages are 500 and greater than Tentative ages are assigned to the gravels in the Lonely Dell/Lees Ferry area by correlation with the Machette and Rosholt (1991) dated sequence in eastern Grand Canyon. The a-level gravel (unit gva) correlates with level 7 at greater than 700 ka, b-level gravel (unit gvb) correlates with level 6 at 500 ka, c-level gravel (unit gvc) is equivalent to levels 4–5 at 75–150 ka, and the d-level (unit gvd)

correlates with levels 3–4 which are 10 to 40 ka.

ture (reviewed by Graf, 1983; Webb, 1985).

Climate and deposition of the gravels Pleistocene gravels and related terraces are present as high-level remnants in many river valleys on the southern Colorado Plateau. The relation of gravels to Pleistocene climate, however, is poorly known. Specifically, were the gravels deposited during the glacial periods with cool, moist climate or following glaciation as the landscape adjusted to warmer, drier climate and large changes in vegetation type and density? Evidence from the map area supports the former explanation. The c- and dlevel gravels (units gvc and gvd) are contemporaneous with large landslide and earthflow deposits (units lsc and lsd), suggesting that they were deposited during glacial climates when large-scale mass wasting was enhanced. Indeed, the gravel and mass wasting deposits probably formed during the glacial climates corresponding to oxygen isotope stages 2 around 20-30 ka and stage 6 at

130–150 ka as determined from sediment in deep-ocean cores. LATE HOLOCENE TERRACES AND RELATED DEPOSITS Late Holocene alluvium occupies most of the inner valley of the Paria River. The deposits underlie four terraces that are 2-7 m above the river. The alluvia are separated by disconformities, erosional contacts that truncate underlying beds (fig. 3). Termed cut-and-fill, this stratigraphic relation results from channel cutting by deepening, widening, and realignment followed by filling or aggradation of the channel and partial refilling of the alluvial valley. The fill deposit typically overlaps the near-channel margin of the older alluvium and terrace. Arroyo cutting is the development of an entrenched, rectangular channel, which is the geomorphic or surface expression of a disconformity. The causes of arroyo cutting are debated intensely, the subject of a large, complex body of litera-

The ages of the deposits of the prehistoric (unit pt) and settlement (unit st) terraces were determined mainly by radiocarbon assays of charcoal found in the alluvium. The dates, however, do not fully constrain the ages of either unit. In the case of the prehistoric alluvium, the context and age of the charcoal suggest that deposition was ongoing at 1030–1200 and that deposition had ended before 1220-1290 (table 1, nos. RC2, RC5, RC6). Deposition of the younger settlement alluvium was ongoing around 1640-1870 (table 1, no. RC4). The minimum age of the settlement terrace is 1840–1890, based on germination dates of cottonwood trees on the terrace. An inset stratigraphic relation shows that the historic alluvium was deposited after incision of the settlement alluvium, which began around 1885, as explained below. Beginning in the early

Age and correlation

1940s and lasting until 1980, the modern alluvium was deposited on a floodplain that aggraded throughout the Lonely Dell reach and Paria River basin (Hereford, 1986). The late Holocene alluvial chronology of the map area is similar to several other streams in the southern Colorado Plateau (Hereford, 2002). The stratigraphy and terrace sequence in the map area are present regionally with only minor variation, suggesting the deposits accumulated at about the same time under similar conditions. Regional correlation of the prehistoric alluvium indicates that deposition ended around 1200 when an episode of arroyo cutting, lasting until 1400, incised channels across the southern Colorado Plateau (Hereford, 2002). This disruption of channel systems in the late 12th and 13th centuries was a major factor leading to abandonment of large areas of the plateau by the Anasazi people, ancestors of the Hopi Indians of northern Arizona. Likewise, regional correlation of the settlement alluvium suggests that aggradation in the Lonely Dell area probably

began after 1400, when a shift to valley-fill alluviation occurred regionally. HISTORIC-AGE ARROYO CUTTING CHANNEL FILLING AND FLOODS Near the end of the 19th century, the present settlement terrace was a floodplain of the Paria River. Beginning in 1883, the river channel in the upper Paria River basin began to incise, causing severe problems with irrigation ditches and roads and causing abandonment of several pioneer settlements (Hereford, 1986). The effects of arroyo cutting were evidently not as severe in the Lonely

Dell area. Nonetheless, the channel was deepened as shown by the rebuilding of flood-damaged irrigation dams and the extension of irrigation ditches progressively farther upstream (table 2). The dams were relocated and the irrigation ditches were extended so the inlets to the ditches would again intersect the bed of the river, which was lowered by floods. Anecdotal information concerning the Paria River, adjoining Kanab Creek, and nearby Virgin River (54 and 130 km west-northwest of the study area, respectively), as well as the Southwest in general, relates the initiation of historic-age arroyo cutting to several episodes of large floods (Webb, 1985; Webb and others, 1991; Hereford and others, 1996a). This episodic flooding continued into

the early 20th century on the Paria River and other rivers in the region. Of the 10 largest floods since

1924, eight occurred by 1940 (fig. 4). Photographs of the channel in the map area taken between 1923–1940 show that it was wide, deep, mostly flat floored, and lacked vegetation (Hereford, 1986), which is typical of most streams on the southern Colorado Plateau during arroyo cutting. The alluvium of the historic terrace is the only deposit from the arroyo-cutting period, and it differs from the modern and settlement alluviums. The historic alluvium is evidently not a channel-fill deposit, as it accumulated only in protected sites such as meander scars along the eroded margin of the settlement alluvium. These sites developed as the eroding channel progressively widened the alluvial valley. This depositional setting differs from the modern alluvium, which typically fills and overtops a preexisting channel in exposed sites that remained fixed. It is likely that 1885–1940 was a period of net sediment transport with lit-

tle sediment storage in the channel or on the floodplain, the result of the frequent, large floods that washed sediment through the channel system. The flood history of the Paria River (fig. 4) illustrates the link between floods, arroyo cutting, and subsequent channel filling. The frequency of floods on the Paria River decreased after 1942 in all frequency categories. The 10-year flood, for example, decreased from 410 m<sup>3</sup>/s (14,500 ft<sup>3</sup>/s) during 1923–1941 to 200 m<sup>3</sup>/s (7,060 ft<sup>3</sup>/s) during 1942–1986, coincident with a decrease in the frequency of runoff-producing storms (Graf and others, 1991). Flood frequency also decreased in the adjoining Escalante River basin (100 km north of study area; Webb and Baker, 1987). In the map area, the modern alluvium was deposited shortly after October 1939, based on photographic evidence from the Paria River gaging station (Hereford, 1986). Deposition, therefore, was coincident with and quite probably initiated by the sustained decrease in the size of the 10-year flood. The alluvium accumulated on floodplains throughout the Paria River basin until 1980 when floods (table 2; fig. 4) incised the channel and floodplain, forming the modern terrace. From 1980 to 1997 a low, lightly vegetated floodplain, which is too small to show at map scale, developed in the channel. Floods in 1997 and 1998 severely eroded this floodplain and further eroded the modern terrace.

The effect of floods on alluvial processes in the map area since the mid-1880s suggests that the characteristic cut-and-fill stratigraphy (fig. 3) results from sustained increases or decreases in the occurrence of large floods. An episode of large floods initiates arroyo cutting that is preserved in the stratigraphic record by erosional contacts and temporal breaks. In contrast, episodes of infrequent large floods result in aggradation of the channel and alluvial valley by basin-wide sediment storage on floodplains, producing a sequence of regionally correlative deposits. Climate controls flood frequency through its influence on runoff-producing precipitation.

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